DEPARTMENT OF DEFENCE

ROYAL AUSTRALIAN AIR FORCE

AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

FORMAL REPORT - PROJECT E2409 catt:000786

KIOWA ASSESSMENT OF PERFORMANCE WITH AN OH-58 BENDIX POWER TURBINE GOVERNOR

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SUMMARY

The ADF's Bell 206B-1 Kiowa helicopter fleet had incurred an increasing number of engine malfunctions attributable to the engine's ageing CECO governor system. A Bendix fuel control unit (FCU) was successfully trialed to replace the CECO systems during flight testing at ARDU in Aug/Sep 99. However, compressor stall incidents continued to occur and a portion of the modified fleet encountered N2 variations where the N2 range would settle at a lower range (outside of limits) after a warm-up period. Subsequently it was found that the Bendix Power Turbine Governors (PTG) fitted by Modification 7113.013-220 were not configured for optimal fuel scheduling for the Kiowa. The current fleet Bendix PTG was calibrated for a Jet Ranger fuel scheduling, which was 3% lower than the Kiowa due, primarily, to the Kiowa's larger rotor diameter. Bell, in conjunction with Honeywell and Rolls Royce recommended fitting the OH58 Bendix PTG to provide the required fuel scheduling.

A quantitative and qualitative assessment against the previous test results for the Bendix FCU characteristics was conducted as a baseline to ascertain the compatibility of the new PTG. The modified Bendix FCU configuration was evaluated for its suitability for the operational reconnaissance and training roles over 6.9 flying hours at RAAF Base Fairbairn during the period 12 – 13 Dec 00. There were improvements in both the static and transient droop characteristics of the modified Bendix system over the entire flight envelope. Within the scope of the testing the susceptibility of the engine towards compressor stalling was reduced and could not be induced during any of the air or ground serials conducted. Careful pilot handling remains a requirement during throttle accelerations both on the ground and in recovery from practice autorotations due to the high sensitivity of the throttle.

The modified Bendix FCU configuration is suitable for both operational reconnaissance and training roles with the Kiowa. The modified Bendix FCU configuration should be incorporated across the ADF Kiowa fleet and that there are no significant performance differences that will require a change to operational procedures upon installation.

1. INTRODUCTION

1.1. Background

1.1.1 The ADF's Bell 206B-1 Kiowa helicopter fleet had incurred an increasing number of engine malfunctions attributable to the engine's ageing CECO governor system. A Bendix fuel control unit (FCU) was successfully trialed to replace the CECO systems during flight testing at ARDU in Aug/Sep 99. The testing found the Bendix system to be a more robust governing system and that it was suitable for operational use with a requirement for some initial operator training to overcome ingrained methods used to account for the CECOs deficiencies. However, compressor stall incidents continued to occur and a portion of the modified fleet encountered N2 variations where the N2 range would vary after a warm-up period. Subsequently it was found that the Bendix Power Turbine Governors (PTG) fitted to Kiowa by Modification 7113.013-220 was not configured for optimal fuel scheduling for the Kiowa. The current Bendix PTG fitted has been calibrated for a Jet Ranger fuel scheduling, which is 3% lower than the Kiowa due to the Kiowa's larger rotor diameter. Bell, in conjunction with Honeywell and Rolls Royce recommended fitting the OH58 Bendix PTG to provide the required fuel scheduling. T&E activities were requested at references A and B on 6 Dec 00, resulting in the initiation of this project, via reference C on 8 Dec 00.

1.2. Project Objectives

1.2.1. The trial objectives assigned to CDR ARDU at reference B were:

a. Conduct a qualitative assessment of the governing system to ensure there were no significant performance differences from the initial Bendix assessment; and

b. Determine if there were any characteristics of the revised governor system, which would require a change to procedures or highlighting to pilots.

1.3. Definition of Terms Abbreviations and Symbols

1.3.1. All terms used in the conclusions and recommendations of this report are defined at annex A. All abbreviations used in this report are defined at annex B.

2. RELEVANT CONDITIONS

2.1. Description of Test Aircraft

2.1.1. The Bell 206B-1 Kiowa was employed by the Australian Army as a Light Observation and Reconnaissance helicopter. On operations, the aircraft was typically deployed either independently or as part of a troop (three aircraft), operating in front of an advancing formation and depended heavily on its manoeuvrability for its self-protection. The Kiowa was a five-seat helicopter configured with a two-bladed teetering head main rotor and two bladed delta-hinged tail rotor. The aircraft was powered by an Allison 250-C20 turbo-shaft, free turbine engine, de-rated from 400 SHP to 350 SHP (at sea level) with a normal operating transmission limit of 317 SHP. The cockpit of the Kiowa provided side by side seating for two aircrew with dual controls consisting of a hydraulically-assisted cyclic and collective controls (incorporating a hand grip throttle) and mechanical yaw control pedals. The designed maximum internal All Up Weight (AUW) of the helicopter was 3200lb.

2.2. Description of Equipment Tested

2.2.1. The aircraft's Bendix hydro-mechanical engine FCU comprised a N1 turbine gas producer fuel control (GPFC) unit and a N2 Governor (PTG) unit. The GPFC was mechanically connected to the throttle and provided fuel for start and from ground to flight idle and scheduled fuel to sustain the N1 turbine while meeting the maximum requirements of the N2 turbine. The N2 governor was mechanically connected via a droop compensator to the collective lever and scheduled fuel to meet actual power demands and sustain the N2 RPM. Both GPFC and N2 governors sensed compressor discharge pressure, engine speed and engine flight control position to regulate fuel flow. The droop compensator was designed to reduce the transient droop associated with rapid power applications. The Bendix system incorporated a series of pressure accumulators to allow the FCU to operate at higher-pressure differentials to reduce response time to the centrifugal piston actions. The essential difference between the current Bendix PTG (P/N 2524667-15) and the OH-58 Bendix PTG (P/N 2524912-5) was that the latter has a top end governing spring of increased stiffness and the throttle lever and shaft were configured differently to facilitate the higher governing range. Research by Army LM Sqn showed that the OH-58 PTG's top end fuel schedule was matched to meet the Bell 206B-1 Kiowa's N2 governing requirements and was the FCU configuration used on the US Army's OH-58 A and C model Kiowas.

2.3. Instrumentation and Test Equipment

2.3.1. A stopwatch was used for timing specific test events. A "lip-stick" camera was fitted via a post-light to the centre structural support between the pilot's seats. The camera was focused to capture the engine gauges. Recording equipment was securely stowed in the rear cabin. These items were treated as aircrew "carry-on equipment". All data was recorded manually on data cards and verified using video footage where required.

2.4. Non-Standard Modifications

2.4.1. No Non-Standard Modifications (NSMs) were required for the testing. Army LM SQN issued deviation A17/123 to allow the completion of task flying without the requirement for ARDU to issue an NSM. Additionally, the camera and recording equipment was installed and operated daily by aircrew as "carry-on equipment".

2.5. Data Reduction

2.5.1. Data reduction was carried out using Microsoft Excel software.

2.6. General

2.6.1. **Crew Experience.** The following flight crew were involved in the task:

Table 2.7.1: Crew and Experience

Serial (a)	Crew Member (b)	Qualification (c)	Flying Hours – all types (as at 13 Dec 00) (d)	Aircraft Hours - on Type (as at 13 Dec 00) (e)
1	MAJ PA Keys	qtp	3500	1920
2	SQNLDR G Maguire	ftn	1800	6.0

2.6.2. **Weather.** Weather conditions for each test are detailed in the Test and Test Conditions table at annex C.

2.6.3. **Time and Place**. The test aircraft was flown at RAAF Fairbairn, 12 and 13 Dec 00. One work-up flight was conducted prior to testing. One maintenance test flight and three project test flights were flown for a total of 6.9 flight hours.

3. TESTS MADE

3.1. Scope of Test

3.1.1. **General.** Project E2409 consisted of a work-up flight, a maintenance test flight and three project test flights. The work-up flight was flown using a ADFHS aircraft fitted with the standard fleet Bendix FCU (hereafter referred to as the original Bendix configuration). The maintenance test flight was conducted post-installation of the OH-58 Bendix Power Turbine Governor (PTG) (hereafter referred to as the modified Bendix configuration). Project flying consisted of same engine assessment tests and representative role tasks as performed on Project E2328 (reference D) with the CECO and the original Bendix FCU systems to qualitatively and quantitatively assess the characteristics of the modified Bendix configuration against the original Bendix configuration. Detailed test and test conditions are presented at annex C.

3.1.2. **Flight Test.** Specific flight tests serials tested the modified-Bendix FCU system from ground level (Fairbairn airfield elevation - 1888ft AMSL) to 10,000ft Hp in ISA+10 and ISA+20°C conditions. Tests were focussed for an assessment of the suitability of the engine governing characteristics for the training and operational reconnaissance roles. All flying was conducted with the aircraft at mid-CG, an average GW of 2710lb in the clean configuration, two-aircrew and with front doors off. Engine bleed air systems were selected on and off during testing as detailed in annex D.

3.2. Test Limitations

3.2.1. The following test limitations applied to all Project E2409 test flights:

a. The maximum rate of throttle application during accelerations from ground to flight idle during ground operations was limited to 40psi torque;

b. The maximum rate of collective application during transient droop testing from minimum power applied in descent to full power (74.3psi torque) was 3 seconds and the minimum N2 limit was 98% for test purposes;

c. The conduct of in-flight operation with the engine fuel control system in manual mode (manual fuel operations) was limited to recoveries from simulated governor malfunctions within gliding distance of the ADFHS lanes;

d. The maximum rate of flight or engine control application was firstly limited by the normal engine or transmission limits, as detailed in reference C;

e. Aborted autorotations conducted initially with full power applied to overshoot, then to a five-foot hover taxi and finally with the use of partial power to arrest the ROD prior to a run-on landing; and

f. The conduct of engine shutdowns and re-starts airborne was limited to VMC and was preceded by a full autorotation work-up and flight of both 5000 and 10000ft AMSL autorotation profiles to ground level with re-start touch drills.

3.3. Method of Test

3.3.1. **Ground Tests.** Ground testing consisted of start, shutdown, and governor acceleration and deceleration characteristics using both throttle and N2 engine trim switch. These were conducted both into and downwind IAW reference G, in the conditions detailed in annex C.

3.3.2. **Flight Tests.** Acceptance testing consisted of normal ground and air maintenance test flight procedures conducted IAW reference F, to ensure the Bendix FCU system was operating normally prior to any Project test flying. Project flight tests were conducted IAW reference D, as summarised in annex C.

3.3.3. **Autorotation Training Test Serials.** The suitability of the modified FCU acceleration characteristics for recovery from autorotation training serials was evaluated quantitatively in three separate phases at normal training weights. The first phase of testing involved full power recoveries initiated with the throttle at ground idle during autorotative descent at 60 KIAS and again at approximately 30 KIAS (to simulate an excessively early flare), in both cases prior to the application of any "initial" collective pitch-pull. Phase two of the testing involved full power recoveries to a 5 to 10ft AGL hover taxi initiated immediately after application of "initial" (one to two-inch collective applications considered that normally applied during autorotational landings with 10 knots through the disc on touch down). Phase 3 of the testing involved "partial power" recoveries to a run-on landing using a rapid application of 1/3 to ½-throttle openings immediately following the initial application to reduce or prevent rotor RPM decay respectively to effect a safe recovery from an incorrect autorotation landing technique. Build-up to a test end-point involved opening the throttle with increasing speed and/or applying an incrementally larger "initial" and noting the resulting governor (torque/Nr) response.

4. RESULTS AND DISCUSSION

4.1. Engine Starts

4.1.1. Engine starts were conducted with the aircraft positioned into wind and down-wind for both cold and hot engine start serials at an average 2100ft Hp in ISA+20°C conditions, IAW reference E. Time until maximum TOT peak, until start was complete and the final idle N1 speed were all consistent between configurations in all conditions tested. The characteristic inherent with the original Bendix FCU configuration of only a single TOT peak was also prevalent with the OH-

58 PTG fitted. The maximum engine temperature recorded during start with the modified Bendix system was 840°C with the engine hot (approximately two minute cool down period from a shutdown) and the aircraft positioned out of wind (12kts tailwind). Overall, the starts with the modified Bendix configuration were marginally hotter than the original Bendix configuration, however, this was likely due to the additional +10 to 15°C temperature delta between test conditions experienced. Within the scope of the tests, the start/acceleration characteristics of the modified Bendix FCU were satisfactory.

4.2. Engine Acceleration

4.2.1. The engine's ground acceleration characteristics with the modified Bendix FCU were evaluated during throttle manipulations from ground to flight idle with decreasing time increments until approximately 40psi torque was reached. Torque, TOT and N1 spool up values and response times versus throttle application rate were consistent with the original Bendix FCU configuration. Hence, the modified Bendix configured engine still required a minimum of 10 seconds to accelerate from ground to flight idle within limitations and remained sensitive to abrupt torque spikes from non-linear throttle application rates. The modified Bendix FCU acceleration characteristics require a high level of pilot care to accelerate the engine during ground run-up to prevent transmission over-torques or inadvertent yawing of the aircraft. The ground acceleration characteristics of the modified Bendix FCU configuration were satisfactory. It is recommended that for operations with the modified Bendix FCU fitted the following caution is incorporated into sections five and E of references G and H respectively (Essential):

CAUTION

Engine accelerations from ground to flight idle during ground operations requires close monitoring of transmission torque and a maximum throttle application rate commensurate with a maximum of 30psi torque (equivalent to approximately 10 seconds from ground to flight idle) to prevent inadvertent aircraft movement or exceeding aircraft limits.

4.3. N2 Trimming

4.3.1. The N2 trim characteristics were evaluated with the heater and engine de-ice on and off. Trim inputs of 1, 2, 3 and 4 seconds were made at 2100ft Hp in ISA+20°C conditions. There was a favourable reduction of approximately one-second in the delay from engine beeper trim application to N2 response times of the modified Bendix FCU configuration. There were insignificant differences observed in the relative change in torque or N2 associated with a trim application. The N2 range was noted after each start and before each shutdown and remained within the 97-104% $\pm$0.5% allowable range throughout all testing. No appreciable trend was observed, however, the maximum variation observed was $\pm$0.3%. The modified Bendix FCU system N2 trim characteristics were satisfactory.

4.4. Static Droop

4.4.1. The engine governing static droop characteristics were evaluated with the engine de-ice on and off for modified-Bendix FCU with progressive full power input tests in zero speed vertical climbs, mission manoeuvres up to 90 KIAS and as a fall-out of specific transient droop testing at 3000 and 10000ft Hp. The power increases from flat-pitch at flight idle to the 5-minute torque limit at 2100ft Hp in ISA+20°C conditions were performed incrementally to reveal any static variation while minimising hysteresis effects. The results of these tests are shown pictorially against the original configuration test results in annexes D and E. These test results show the modified-Bendix FCU to be a more consistent system with regard to power changes. Qualitatively, the modified Bendix FCU configuration produced less static variation than the original configuration due to power and airspeed changes during aggressive mission manoeuvres. The modified-Bendix FCU displayed the characteristic of the original configuration in that the N2 oscillated ±½% around the trim setting for several seconds following aggressive use of power, and in addition it displayed a similar characteristic to a lesser extent (±¼%) with only moderate (±5psi) power applications. This characteristic is likely the result of reduced damping inherent with the increased operating gains of the modified Bendix PTG and is not considered a detrimental characteristic. The modified Bendix configuration's improved static droop governing characteristics will reduce pilot workload in all tasks from simple circuit operations to aggressive mission manoeuvres involving rapid power and airspeed changes to enable manoeuvring without undue distraction. The improved static droop characteristics of the modified Bendix FCU configuration were an enhancing feature for the reconnaissance/training roles. Recommend incorporation of the modified Bendix FCU configuration across the ADF Kiowa fleet.

4.5. Transient Droop

4.5.1. The FCU transient droop characteristics were evaluated quantitatively at 1,000 and 10,000ft Hp in ISA+20°C conditions with the engine de-ice on and off. The tests involved full power, constant-rate power applications performed at incrementally faster rates from minimum power in descent (N2/Nr needles just joined) to approximately 63psi torque at 60 KIAS. The results are displayed in hand-drawn plots at annex E. Additionally, the transient droop characteristics were assessed qualitatively during reconnaissance mission manoeuvres at varying degrees of aggressiveness. During the 1,000 and 10,000ft Hp quantitative tests there was a small but positive (approximately 10%) improvement of the transient droop characteristics of the modified configuration over the original FCU configuration. The modified Bendix FCU was capable of accelerating within transient limits with full power applications to a minimum of 99% N2 at the maximum rate of 3.0 and 3.5 seconds at the 3000 and 10000ft Hp points respectively. This compared favourably to the original Bendix FCU, which remained within limits at the slower 5 and 6 seconds applications at 3000 and 10000ft Hp respectively. The modified FCU's transient droop characteristics were affected by the operational status of the engine bleed air systems by a maximum of 0.5% N2. Qualitatively, during aggressive mission manoeuvres at 2200ft Hp in ISA+20°C conditions the transient droop characteristics of the modified-Bendix FCU showed a moderate improvement over the original configuration. The improved transient droop characteristics of the modified Bendix FCU configuration will allow the reconnaissance pilot to manoeuvre aggressively without undue distraction. The transient droop characteristics of the modified-Bendix FCU were satisfactory for the reconnaissance/training roles.

4.6. Drive Train Instability

4.6.1. The tendency of the damping characteristics of the modified Bendix FCU configuration to induce instability within the aircraft's drive train was assessed with a series of engineering tests. Tests comprised collective ramp, step, doublet and low amplitude sweep inputs at progressively faster rates at 3000 and 10000ft Hp in ISA+20°C conditions. The modified Bendix FCU exhibited well-damped governing characteristics to all tests and displayed no tendency towards inducing instability within the airframe. The governing characteristics of the modified Bendix FCU with regard to drive-train stability were satisfactory.

4.7. Autorotation Training

4.7.1. **Full Power Aborts.** The suitability of the modified Bendix FCU's acceleration characteristics for the conduct of full power aborts during practice autorotation training was evaluated quantitatively in two phases at normal training weights as described in section 3.3 (Method of Test). Overall, the maximum transmission torque generated during full power recoveries from an autorotation was slightly higher to that produced by the original Bendix FCU configuration system. Full power recoveries prior to the application of any "initial" pitch could still be effected down to a minimum one-second throttle opening and remain comfortably within limits. Full power aborts at 60 KIAS showed no appreciable difference in torque and N2/Nr response (maximum of 30psi and 107%/375RPM). Full power aborts at 30 KIAS (mid-flare), however, required moderate intervention with collective to perform a one-second-throttle application and remain within limits (maximum of 40psi and 108%/380RPM with a two-inch collective application). In this regard the modified Bendix configuration compared less favourably with the original configuration which produced just 35psi torque and required no collective intervention. Full power recoveries to a hover-taxi following application of "initial" *were only achievable in conditions requiring a maximum of two-inches initial pitch* (equivalent to conditions and technique producing a minimum of 15 knots through the rotor disc at touch-down). A three-second minimum throttle opening rate was still required to provide comfortable torque margins. The sensitive response of the Bendix FCU will require increased care by QHIs to effect full power abort from an autorotation below 40KIAS and particularly after the application of "initial" pitch. The acceleration characteristics of the modified Bendix FCU configuration to effect full power recoveries from practice autorotation training above 30KIAS were satisfactory. It is recommended that for operations with the Bendix FCU fitted that the following caution be incorporated into the Kiowa Instructor Standardisation Guide (Essential).

CAUTION

During practice autorotations, full power recoveries (with the modified-Bendix FCU configuration) are not recommended following application of an initial pitch greater than 2-inches (a 2-inch "initial" is assessed as that required for a autorotative landing in 10 knots of wind at training weights).

4.7.2. **Partial Power Aborts.** The suitability of the modified Bendix FCU's acceleration characteristics for the conduct of partial power aborts to a running landing during practice autorotation training was evaluated quantitatively in two phases at normal training weights as described in section 3.3 (Method of Test). Partial power recoveries to a running landing involving a ½-second, one third and one half-throttle opening (or "tweak") immediately prior to cushioning the landing and resulted in comparable torque increases between the original and modified Bendix FCU systems. The technique was easily performed within limits with a full ½-throttle "tweak" application immediately following a large (three-inch) initial pitch application resulted in a maximum 40psi torque response. The smaller 1/3-throttle "tweak" consistently slowed the rate of Nr decay during the landing phase and prevented N2/Nr from bleeding below 73%/240RPM. The larger ½-throttle "tweak" slowed the rate of decay considerably and consistently prevented N2/Nr from bleeding below85%/280RPM which provided a substantial margins for effecting recovery under all test performed to simulate common student errors. The governing characteristic of the modified Bendix FCU configuration will enable the QHI to prevent damaging an aircraft due to adverse wind conditions or incorrect student technique in the final moments of practice autorotational landings. The acceleration characteristics of the modified Bendix FCU configuration for partial power recoveries from practice autorotations were satisfactory. It is recommended that the modified Bendix FCU configuration be incorporated across the ADF Kiowa fleet and that the partial power recovery technique be incorporated into Kiowa Standardisation Guide, reference I

(Highly Desirable).

4.8. Engine Air Restarts

4.8.1. Engine air shutdowns and restarts were conducted IAW reference E at 5000 and 10000 ft Hp in ISA+20°C conditions with the modified-Bendix FCU installed. The Bendix air-restart technique involved opening the throttle initially to idle only to observe the initial TOT peak and was used for both re-start serials without incident. The modified Bendix configuration exhibited the same reducing peak-TOT trend with increased DA during engine air restarts as the original Bendix configuration. This allowed airborne restarts to be successfully completed throughout the altitude range of the aircraft's operating envelope. The peak TOT(s) encountered during the relight serials were approximately 150°C hotter (860°C at 5000ft Hp in ISA+20°C) than during the previously tested serials with the original Bendix configuration. This is believed to be due to the trial conditions being some 15°C warmer (ISA+20°C during the CB testing as compared to the ISA+5°C during original Bendix FCU trial). The trend encountered with increasing time between shutdown and commencement of the relight was that the peak TOT and the time to effect a relight increased notably. The difference between a 15 and a 25-second interval from shutdown to commencing the relight resulted in an additional 30°C TOT rise and a further 10 seconds to complete the start in the same conditions. The engine air-restart characteristics of the modified Bendix configuration were satisfactory. Recommend incorporation of the following Cautions into references G and H (Essential).

CAUTION

A height of 2000ft AO is considered the minimum required to effect an engine air restart as airborne relights to full power for recovery can take up to one minute.

CAUTION

Attempts at engine air relights should be commenced without undue delay. Delays in excess of 30 seconds increase the risk of catastrophic engine damage and/or increased height loss to effect a restart.

4.9. Manual Fuel Recovery

4.9.1. The acceleration and damping characteristics in manual fuel operation were evaluated from within a circuit between zero and 90KIAS at an average 2500ft Hp in ISA+20°C conditions. Recoveries were flown to an approach to a vertical and running landing. The Bendix FCU is not capable of simulating a "manual fuel" degraded mode of the engine governing system in the same respect as the CECO FCU could. Even with large reductions in throttle position from flight idle the PTG continues to attempt to schedule fuel in response to collective position in the same way as the S-70A-9 engine's HMU provide gross fuel scheduling in ECU lockout. As a result the standardised manual fuel technique of setting torque by throttle position and controlling Nr with collective is incompatible as collective inputs vary torque. However, for the purpose of training for the coordination required to effect a recover from a degraded PTG in "manual fuel" mode, sufficient control of N2 is achievable through manipulating the throttle to enable effective manual fuel training. By amending the current standardised technique to the previously taught Kiowa technique of using collective to control N2/Nr and coordinating throttle and collective inputs to set power required the modified Bendix configuration allows for the maintenance of a critical degraded mode skill. The throttle in the modified Bendix configuration remains slightly more sensitive than in the CECO FCU configuration and requires a smooth and deliberate technique to remain within normal N2 tolerances. The characteristics of the modified Bendix configuration in simulated manual fuel mode were satisfactory to allow the conduct of manual fuel recoveries for training purposes. It is recommended that the conduct of manual fuel training be incorporated into the Kiowa Standardisation Guides, reference I, and approved for conduct (Highly desirable).

4.10. Engine Shutdown

4.10.1. Engine shutdowns during ground operations were conducted into and downwind at up to 20 knots at 2100ft Hp in ISA+20°C conditions. There were no noticeable differences between the shutdown characteristics of the two Bendix FCU configurations. The shutdown characteristics of the Bendix system were satisfactory.

4.11. Compressor Stalls

4.11.1. The susceptibility of the engine to compressor stall was assessed qualitatively through moderate and aggressive aircraft handling and additionally through throttle manipulations during ground serials. An engine compressor stall was not encountered during any aerial sequences with either Bendix FCU configuration fitted despite manipulating the flight controls to very high aggressiveness levels. Ground serials involving throttle manipulations from ground to flight idle to replicate conditions in which several compressor stalls have been experienced since the original Bendix FCU configuration was incorporated. The ground serials were conducted at moderate and fast throttle application rates. The compressor stalls encountered during the ground serials were only with the original Bendix configuration installed and only when the throttle was manipulated relatively fast in the initial 0-30° of throttle range. The original Bendix configuration was particularly prone to stalling as a result of these fast initial throttle inputs immediately after practice hovering autorotation sequences in which the engine was still decelerating when throttle was first applied. The stalls could not be reproduced using equivalent throttle opening rates in-flight (during partial power practice autorotation landings) with the original Bendix configuration and could not be reproduced under any conditions with the modified Bendix FCU configuration installed. Within the scope of the tests the modified Bendix FCU configuration has reduced the susceptibility of the Kiowa to compressor stalling due to rapid application of throttle from the ground idle position during ground operations.

5. CONCLUSIONS

5.1. General Conclusions

5.1.1. In a comparison of the performance characteristics of the Bendix FCU in the original and modified configurations using previous Bendix test results as the baseline the modified-Bendix FCU was a more responsive and consistent engine governing system with less susceptibility to incur compressor stall during ground serials. The improvements in system performance were more prevalent during manoeuvring at high levels of aggressiveness. Care will still need to be applied during ground accelerations and full/partial power aborts from practice autorotations, however, no significant operator training is necessary and only minor changes to procedures are required following incorporation of the modified Bendix FCU configuration across the ADF Kiowa fleet. The modified-Bendix FCU system is suitable for the operational reconnaissance and training roles.

5.2. Specific Conclusions

5.2.1. The improved static droop characteristics of the modified Bendix FCU configuration were an enhancing characteristic for the reconnaissance/training roles (paragraph 4.4.1)

6. RECOMMENDATIONS

6.1. Recommendations – General

6.1.1. The modified Bendix FCU configuration should be incorporated into the B206B-1 ADF Kiowa fleet as soon as practicable.

6.2. Recommendations - Essential Actions

6.2.1. The following "Cautions" should be incorporated into sections five and E of references G and H:

Paragraph 4.2.1. *CAUTION*

"Engine accelerations from ground to flight idle during ground operations requires close monitoring of transmission torque and a maximum throttle application rate commensurate with a maximum of 30psi torque (equivalent to approximately 10 seconds from ground to flight idle) to prevent inadvertent aircraft movement or exceeding aircraft limits".

Paragraph 4.7.1. *CAUTION*

During practice autorotations, full power recoveries (with the modified-Bendix FCU configuration) are not recommended following application of an initial pitch greater than 2-inches (a 2-inch "initial" is assessed as that required for a autorotative landing in 10 knots of wind at training weights).

Paragraph 4.8.1. *CAUTION*

A height of 2000ft AO is considered the minimum required to effect an engine air restart as airborne relights to full power for recovery can take up to one minute.

CAUTION

Attempts at engine air relights should be commenced without undue delay. Delays in excess of 30 seconds increase the risk of catastrophic engine damage and/or increased height loss to effect a restart.

6.3. Recommendations – Highly Desirable

6.3.1. The partial power recovery technique should be incorporated into the Kiowa Standardisation Guide (paragraph 4.7.2).

6.3.2. The conduct of manual fuel training be incorporated into the Kiowa Standardisation Guides, reference I, and approved for conduct (paragraph 4.9.1).

7. REFERENCES

A. 1500-22-12 HQ Avn Spt Gp 1501/00 dated 6 Dec 00

B. ARMYLMS/4917/A17/2630/99 Pt2 (2) dated 6 Dec 00

C. ARDU 2700/E2409 TECH Pt 1 (4) dated 8 Dec 00

D. ARDU Project E2328 Formal Report dated 19 Feb 00

E. ARDU Project E2409 Task Plan dated 11 Dec 00

F. AAP 7210.010.6-15 Flight Test Schedule Bell 206B-1 AL3 dated 22 Aug 83

G. AAP 7210.010-1 Flight Manual Bell 206B-1 AL 0 dated 11 Sep 00

H. AAP 7210.010-1CL Pilot Checklist Bell 206B-1 AL 0 dated 11 Sep 00

I. AAVN Kiowa Standardisation Guides

8. PROJECT PERSONNEL

8.1.1. Project personnel were as follows:

a. Project Manager and Pilot: MAJ PA. Keys, qtp, AAvn1, ARDU

b. Project FTE: SQNLDR G. Maguire, BEng, ftn, TT1, ARDU

c. Project Coordinator: Mr K. Holst, AAVN PC ARDU

TEST AND TEST CONDITIONS

Ground Testing

Serial (a)	Task (b)	Height (ft AGL) (c)	Airspeed (KIAS) (d)	Comments (e)
1	Starts & Shutdowns	0	-	Into wind downwind **(1)** No modulated starts performed in 12 and 20 knot winds at ISA+20°C
2	Accelerations	0	-	From ground to flight idle in 15,12,10 seconds. Varying rate of initial application to replicate compressor stall conditions
3	Engine Trim	0	-	Application of N2 beep switch at 100% RRPM for 1,2, 3 & 4 second intervals noting delays and final N2

Note: (1). Conducted with engine cold and hot (restart two minutes after shutdown)

Work-up Flying

Serial (a)	Task (b)	Height (ft AGL) (c)	Airspeed (KIAS) (d)	Comments **(1)** (e)
1	Mission Manoeuvres	0-200	0-100	Quickstops; Masking/Unmasking; Accel/Decels; Jump Take-offs; Max Performance Manoeuvring
2	Manual Fuel Recoveries	500-0	100-0	N2 governor malfunction simulated by increasing N2 beep & manually controlling RRPM/Engine RPM with throttle movements to effect a zero speed landing
3	Transient Droop Testing	1000	60	Maximum torque of 70psi. Full power application pulls of 8,6,4, & 3 seconds.
4	Practice Forced Landings (PFLs)	5000 & 1000	100-0	Straight-in, 180°, 360° to a pre-inspected point on the airfield
5	Hovering Autorotations	0-10	0-20	Including Hover-taxi Autos
6	Power Termination Autorotations	10-500	60-0	Including full and partial power aborts up to & including the initial pitch-pull during the flare
7	Autorotations to Touch-down	0-500	60-0	

Note: (1). All "Work-up" serials flown with the original Bendix FCU configuration installed.

Project Flying

Serial (a)	Task (b)	Height (ft AMSL) (c)	Airspeed (KIAS) (d)	Comments **(1) (2)** (e)
1	Engine Trim	0-500	0-120	N2 trim application requirements during circuit type ops
2	Static Droop	0-500 & 10,000	0	Increase power in 5 psi torque increments from MPOG, noting static N2/RRPM
3	Transient Droop	1000 & 10,000	60	Initiate full power climb from min power descent (N2/RRPM just joined) in 8,6,4,3 second intervals.
4	Drive-train Stability Testing	1000 & 10,000	60	±10 PSI Ramp, Step, Doublet, Low Amplitude Sweep collective inputs from ¼ to 1Hz in ¼Hz increments.
5	Roll Reversals	1000	60-100	Max 60° AOB, increase roll rate (Lt & Rt) in 15°/sec increments to a max roll rate of 60°/sec.
6	Autorotative Landing Aborts	500-10	0-60	Recover using full throttle applications during flare with zero power applied in 4, 3, & 2 second intervals and repeated with partial throttle applications with 2 & 3" initial collective pitch applied during the flare (prior to introduction of throttle) **(3)**.
7	Unmask/ mask	50-100	30 KEAS	Lateral and vertical ±50ft
9	Accel/Decel	50	0-40-0	Rapid re-positioning between OGE Ops using no more than ±20° aircraft attitude change or 70 psi torque.
10	Quickstops	50-100	100-0	Maximum AOB of 60°, maximum attitude of 30° nose up
11	Manual Fuel Recoveries	500-0	100-0	Recovery from a simulated governor over-speed emergency to a zero speed landing.
12	Engine Air Re-starts	5000 & 10000 2500, 3500, 6000 & 10000	80	Conducted overhead CB airfield. **(4)**

Notes:

(1) Rate of engine/flight control application was firstly limited by the engine, transmission and/or airframe limits stated within reference G.

(2) Test conducted firstly with bleed air systems (ENG DE-ICE & Heater) off and again with the systems on.

(3) Full power recoveries flown to a full power climb or hover taxi (not below 5ft AGL) and partial power recoveries flown to a running landing using 1/3 and ½ throttle applications in 0.5seconds.

(4) Airborne engine shutdowns completed after 5 minutes of level flight at $V_{MIN\ DRAG}$ to stabilise engine oil temperatures and restart initiated within maximum of 40seconds of the shutdown to prevent seizure of the Gas Producer Turbine section.

DEFINITION OF TERMS

Table A-1: Terms Used in Conclusions and Recommendations

DESCRIPTION OF DEFICIENCY	CONCLUSION	RECOMMENDATION TERMINOLOGY	RECOMMENDATION LEVEL
Prevents aircraft performing operational task or liable to cause accidents - restrictions needed to prevent occurrence are considered intolerable.	UNACCEPTABLE	Something must be done.	ESSENTIAL
Restricts aircraft's operational capability or is liable to cause accidents unless significant restrictions are imposed.	UNSATISFACTORY	Something should be done.	HIGHLY DESIRABLE
Should be improved to make a safer or more capable aircraft.	UNSATISFACTORY	Something should be done.	DESIRABLE
Satisfactory without improvement.	SATISFACTORY	No action.	No action.
Characteristic which improves the operational capability or safety of the design.	ENHANCING CHARACTERISTIC	Should be incorporated in future designs.	Desirable to incorporate in future designs.

LIST OF ABBREVIATIONS AND SYMBOLS

Table B-1: List of Abbreviations and Symbols

ABBREVIATION OR SYMBOL	DEFINITION
ADF	Australian Defence Force
ADFHS	ADF Helicopter School
AMSL	Above Mean Sea Level
ARDU	Aircraft Research and Development Unit
Army LM Sqn	Army Logistics Management Squadron
AUW	All Up Weight
BEng(Aero)	Bachelor of Aerospace Engineering
CG	Center of Gravity
DA	Density Altitudes
EMI/C	Electromagnetic Interference/Compatibility
FCU	Fuel Control Unit
fte/ftn	Flight Test Engineer/Navigator
GPFC	Gas Producer Fuel Control
GW	Gross Weight
ISA	International Standard Atmosphere
Hp	Pressure Altitude (1013 hpa)
HQ Avn Spt Gp	Headquarters Aviation Support Group
lb	Pounds Mass
MPOG	Minimum Pitch On Ground
N1	Gas Turbine Speed
N2	Power Turbine Speed
NSM	Non-Standard Modification
OPs	Observation Posts
qtp	Qualified Test Pilot
RAAF	Royal Australian Air Force
ROD	Rate of Descent
RPM	Revolutions per Minute
SHP	Shaft Horsepower
T&E	Test and Evaluation
TOT	Turbine Outlet Temperature
VMC	Visual Meteorological Conditions

TEST AND TEST CONDITIONS

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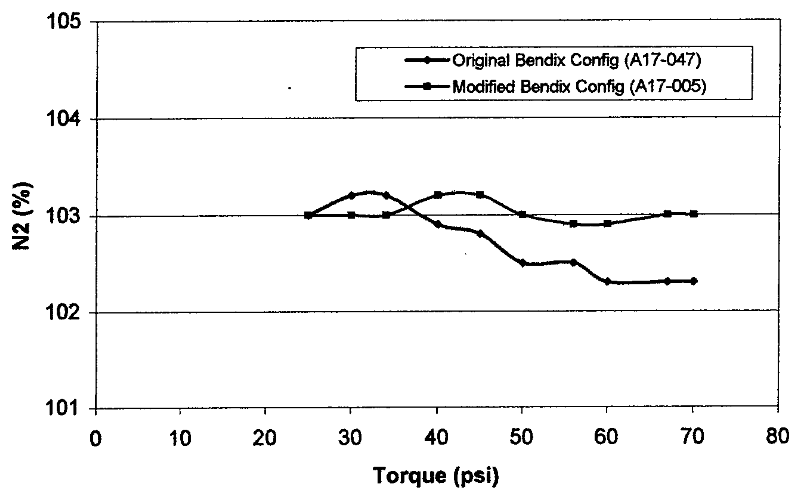
STATIC DROOP

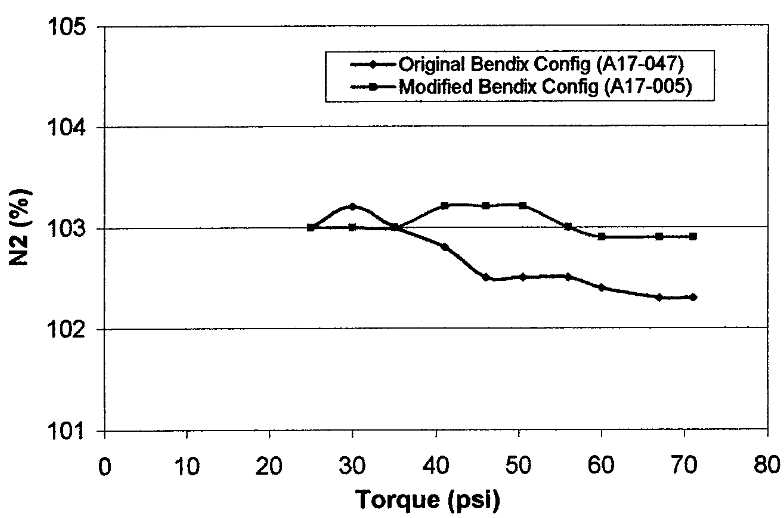
2100ft Hp - ISA+20degC Bell 206B-1 (A17-005) Dec 00 and 300ft Hp - ISA+5degC (A17-047) Sep 99

Engine Bleed Air - OFF



10000ft Hp ISA+20degC (A17-005) & ISA+5degC (A17-047)

Engine Bleed Air - ON



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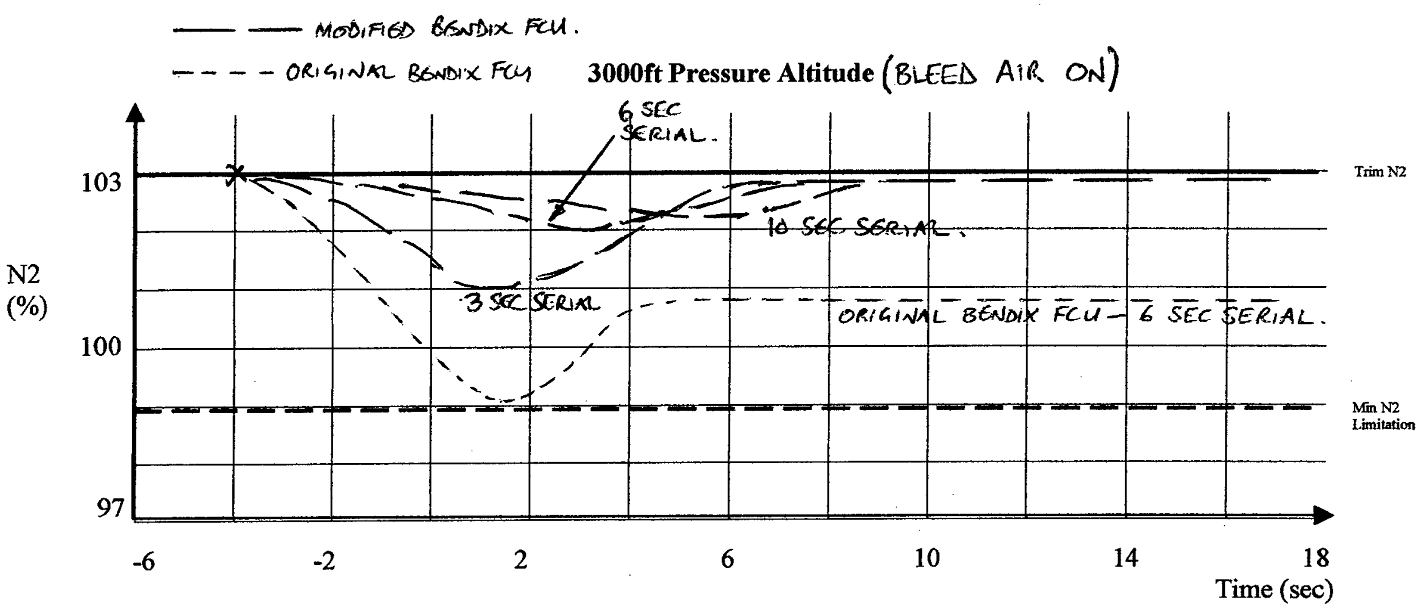
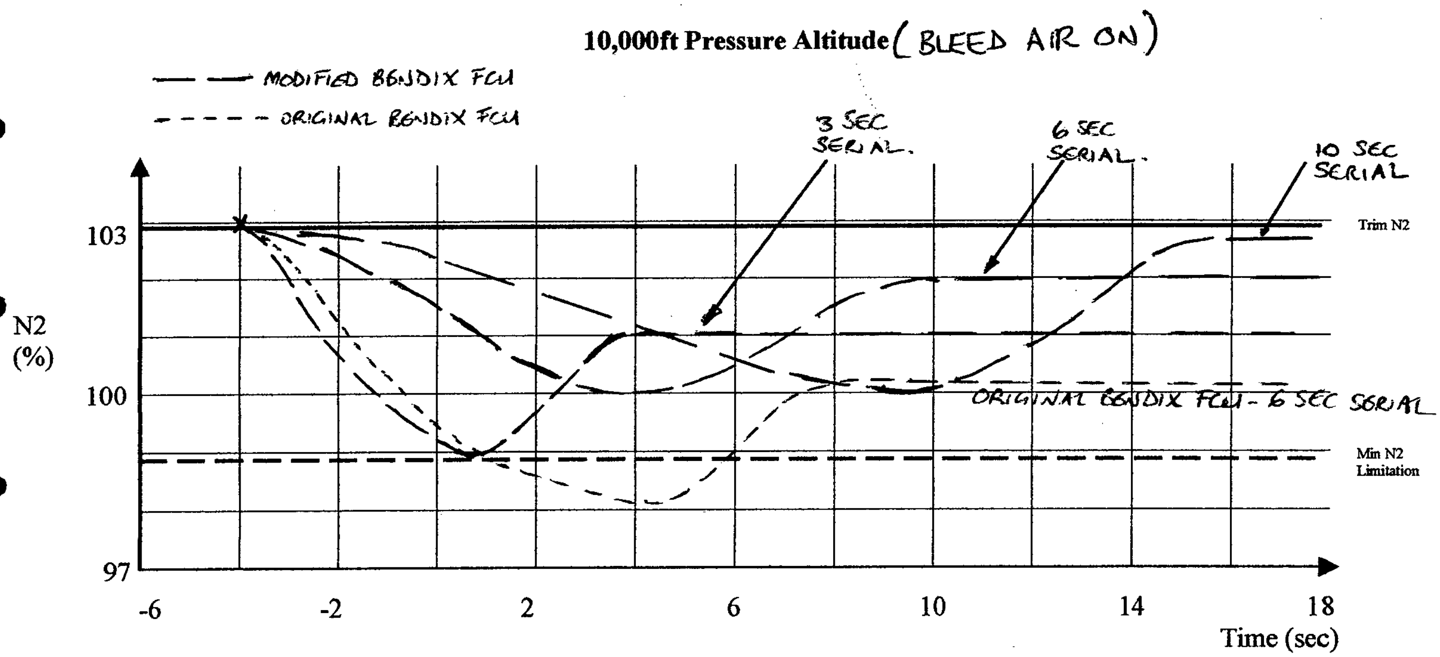
PROJECT 2409

TRANSIENT DROOP CHARACTERISTICS





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ABSTRACT	The ADF's Bell 206B-1 Kiowa helicopter fleet had incurred an increasing number of engine malfunctions attributable to the engine's ageing CECO governor system. The installation of the Bendix system was investigated in late 1998 and an assessment by direct comparison was conducted in Aug 99. The Bendix system displayed superior characteristics, particularly at the extremes of the aircraft's manoeuvrability and altitude envelope and was incorporated into the fleet. Subsequently, some of the aircraft demonstrated non-repeatable N2 variations and Bell proposed fitment of the OH-58 PTG. Trial of the modified Bendix FCU successfully took place in Dec 00 which demonstrated no tendency towards N2 variations and displayed improved transient and static droop characteristics over the original Bendix FCU configuration.